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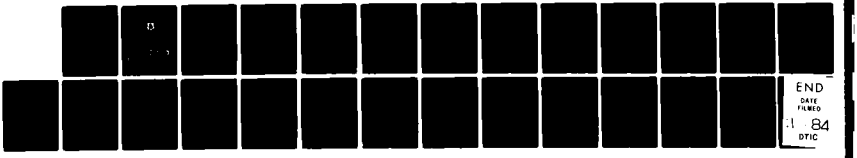

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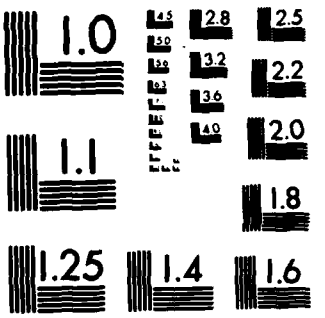

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PROPERTIES OF AEROSOLS DURING A DUST STORM OVER THE BEIJING AREA

by

Zhou Mingyu, Qu Shaohou, et al

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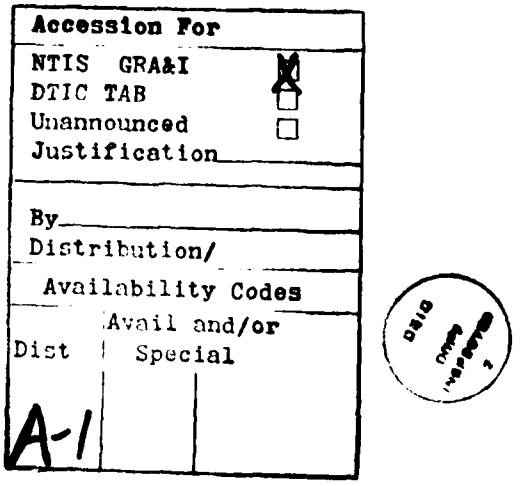

PROPERTIES OF AEROSOLS DURING A DUST STORM OVER THE BEIJING AREA

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Submitted 22 November 1980

ABSTRACT

In this paper some characteristics of the aerosal in a dust storm occurring April 18—20, 1980, over Beijing area were described. Analysis of meteorological data showed that the dust storm was formed in Hami area of Xingjiang Province and western part of Inner Mongolia. The strong wind area moved first toward east and then southeast when it reached central part of the Inner Mongolia and Hebei Province. By means of the 325-meter observation tower and radiosounding technique the Structure of atmospheric boundary layer was discussed for the dust storm.

The aerosol Concentration of this dust storm much larger than usual by anorder of magnitude. Elemental concentration in aerosol was obtained by using neutron activation analysis. Analytical results indicated that elements Eu and Ta existed only in aerosol of this dust storm and the other elements appeared both in the normal aerosol and in the dust storm aerosol. Calculation of enrichment factor showed that elements Sc, As, Br, Sb came mainly from coal combustion.

From discussion of the meteorological background of the dust storm formation and the analysis of the elements in aerosols it can be considered that the dust storm aerosol was made of soil particles brought and mixed by the strong wind into the atmosphere the particles are of the areas where the strong wind formed and passed.

I. Foreword

As revealed in observations of aerosol constituents in recent years [1, 2], aerosols in the atmosphere can be transported over a long distance. The atmospheric boundary layer of 1-2 km altitude near the ground plays a major role in transporting contaminants in the atmosphere because the atmospheric boundary layer is the zone where materials transported between high altitudes and the ground (and vice versa) must pass. This transport process is closely related to weather conditions.

Aerosols of different sources have different physical and chemical properties; therefore, we analyze the chemical constituents of aerosols, distribution of granularity, and their relationship with weather conditions to discuss sources of aerosols with different properties and the transport rule in the atmosphere.

The authors collected aerosol samples in the atmosphere before and after a dust storm in the afternoon of 18 April 1980 and analyzed the chemical constituents and granularity distribution for discussion of general features of aerosols in the Beijing area and the aerosol properties after this dust storm over Beijing.

II. Observation and Analysis Methods

1. Sampling of aerosols

A model KB-120 air sampler was used to collect aerosol samples; the instrument includes a supporting frame with a filter disc, a vacuum pump, and a flow meter; the pump can pass air with a flow of 60 to 70 liters per minute through Chinese-made Xinhua brand filter paper (corresponding to a Whatman 41 filter paper) with diameter of 30 mm. The collecting efficiency was 98 percent with a low percentage of blank paper and desirable endurance against radiation. Thus, the setup is suitable for analysis of multiple elements in low concentrations. The effective area of sampling is 7.07 square centimeters.

The sampler was placed on a roof deck of a 25-meter high building; the sampling dates were 16 and 17 April 1980 with four samplings in a 24-hour period. Each time, the sampling quantity was 12 cubic meters. From 1500 to 1700 hours on 19 April, samples were collected; the sampling quantity was 7.2 cubic meters. The sampling qiantity in the morning of 20 April and in the morning of 21 April was, respectively, 14.25 and 19.53 cubic meters.

2. Analysis method

An instrument neutron activation method [3] was used for analysis and determination of concentrations of trace elements in the aerosol samples. Since no chemical processing is required in the instrument neutron activation method, contamination or loss of elements during the experimental process can be prevented.

(1) Preparation of samples and standards

The aerosol samples collected on filter paper were first folded and compacted; three layers of high purity aluminum foil wrapped the samples in preparation for radioactive bombardment.

The standard preparations are divided into seven mixed multiple element sections based on nuclear and chemical properties and measurement conditions. In the standard preparation of each section, drops of standard high purity solution are placed on six layers of filter paper with diameter of 9 milli-

meters. After natural drying in a drier, the filter papers are wrapped with high purity aluminum foil, ready for radioactive bombardment.

(2) Radioactive bombardment

The sample and standard preparation were placed in an aluminum can for bombardment; the can was placed in a pipe in a radioactive zone of a swimming pool type reactor at the Qinghua University for ten hours of radioactive bombardment. The neutron flux was 1.3×10^{13} m/cm^2·sec.

(3) Radioactivity measurement and data processing

The radioactivity measurement instrument was a SCORPIO-3000 program-controlled Ge(Li) gamma spectrometer (made by Canberra Corporation of the United States). The effective volume of the detector was 136 cm^3; the discriminability and relative efficiency were, respectively, 1.88 KeV and 28 percent (for gamma rays of 1332 KeV with respect to Co); the peak to valley ratio was 55.5 to 1.

Based on nuclear properties of each radioactive isotope, the gamma energy spectrum of each post-bombardment sample was determined with different decaying time. The spectral data were obtained by a Scorpio processor, and the data were stored on hard magnetic discs of the system; then, a PDP 11/04 computer was used for data processing. The analysis program of the Gammas spectrum used the Scorpio/Spectran software for processing the spectral data. The program includes smoothing the original data, seeking the peak, calculation of peak net area, discrimination of isotopes, and analyses.

After analyzing the Gammas program, the peak net area of various characteristic peaks of nuclear elements was obtained. Following decaying and deduction of calibration due to interference, the sample was then compared with the standard; thus, concentrations of the measured elements in the sample can be calculated.

For accuracy of the measurement method, when the sample was analyzed, comparison was made between the standard reference materials of the U. S. National Bureau of Standards, and values reported in the Literature (refer to Table 1); the data matched quite well. This proves that the method used is reliable.

3. Meteorological observation

In order to analyze the relationship between the aerosol properties and meteorological conditions, the authors utilized data obtained at Madian Weather Station (in the north suburb of Beijing) to analyze the meteorological conditions. In addition, the data obtained at the 325-meter meteorological tower of the station were used to analyze the vertical distribution of wind and temperature in the atmospheric boundary layer and the structure of the layer. There were 15 layers of observation of wind and temperature by the meteorological tower; the altitudes of these layers were 9.7, 15.0, 32.7, 47.7, 63.2, 80.3, 102.7, 120.2, 140.2, 160, 180.1, 200, 240, 279.9 and 320 meters. The distribution of meteorological elements of higher layers was analyzed by using the sounding data obtained by the Beijing Meteorological Observatory.

Table 1. Elemental content of NBS [U. S. National Bureau of Standards] standard reference materials SRM-1632a (ppm).

(a)元素	(b)本工作测定值	(c)文献值	元素(a)	(b)本工作测定值	(c)文献值
Cr	35.1±1.2	34.4±1.8[A]	Co	8.7±0.3	8.8[A]
Fe	11078±128	11100±200[A]	Eu	0.56±0.02	0.54[A]
Se	2.6±0.7	2.6±0.7[A]	Hf	1.57±0.08	1.6[A]
Th	4.46±0.13	4.5±0.1[A]	Rb	33.4±1.5	31[A]
U	1.24±0.02	1.28±0.02[A]	Sc	6.48±0.14	6.3[A]
Sb	0.56±0.07	0.58[A]	K	4200±200	4200±200[A]
Ce	29.2±1.3	30[A]	La	16±2	18±2[B]
Cs	2.3±0.1	2.4[A]	Sm	2.7±0.1	2.8±0.3[B]

Remark: The determination value in the research is the average value of four samples.
A: Certificates of analysis, standard reference materials SRM-1632a, U. S. Bureau of Standards, Department of Commerce, Washington D. C. 20234.
B: Anal. Chem., 52, 240 (1980).
Key: (a) Element; (b) Determination value in this research; (c) Value in Literature.

III. Weather Background of Dust Storm Process

From 18 to 20 April 1980, in the Beijing area, a very intense dust storm broke out. The weather background causing this dust storm was the southward process of an intense current of cold air from Siberia. At 0800 hours on 16 April 1980 on a weather map, a trough area was seen over Siberia; in addition, an intense cold advection was also seen. At the corresponding ground weather map, there was a weak cold front matching the cold advection. At 0800 hours on 17 April on a 500 mb weather map, the trough over Siberia moved to the west of the area from Lake Baykal to Hami in Xinjiang province; in addition, the cold air was constantly intensified. At 1400 hours on 17 April on a ground weather map, a zone of strong wind was formed to the west of Hami (in Xinjiang), Hetao (bend of the Yellow River) and western Inner Mongolia.

On 18 April on a 500 mb weather map, the trough continuously moved eastward to the area of Inner Mongolia and North China, developing into a very intense low pressure in the area of Inner Mongolia and North China. The cold front stayed over the area extending from Ejinuo'er and Hohhot in Inner Mongolia, western Northeast China, and the area of the Yinshan Mountain Range, there was a zone of strong wind. In the afternoon of 18 April, the cold front passed Beijing. At high altitudes, the wind speed was higher than 20 meters per second, but the wind speed near the ground was very low, only 3 to 4 meters per second. Therefore, the sky was yellow for the entire afternoon of 18 April. After 1700 hours on the 18th, the ground wind speed increased rapidly and a very intense dust storm abruptly broke out. The horizontal visibility was only about 1 kilometer.

Since cold air in high altitudes continuously moved from the northwest to the North China area, the intense dust storm persisted for a long time. On 19 April, the dust storm still remained; on 20 April, the storm gradually weakened, until it disappeared on the 21st.

Figure 1 was the route map of the zone of strong wind in the process of the dust storm. In the figure, the zone of strong wind was drawn based on the ground weather maps at 2000 hours on 17, 18 and 19 April. From Fig. 1,

the zone of strong wind appearing in southern Mongolia, eastern Xinjiang, and western Hetao began to move eastward. After the 18th, the zone of strong wind moved southeastward from the area of Inner Mongolia and Hebei.

From the formation and moving process of the zone of strong wind, it seems that this dust storm passing over the Beijing area was caused by soil micro-particles of the aforementioned zone of strong wind that had blown to high altitudes by strong wind, and then the micro-particles moved with the strong wind to the Beijing area.

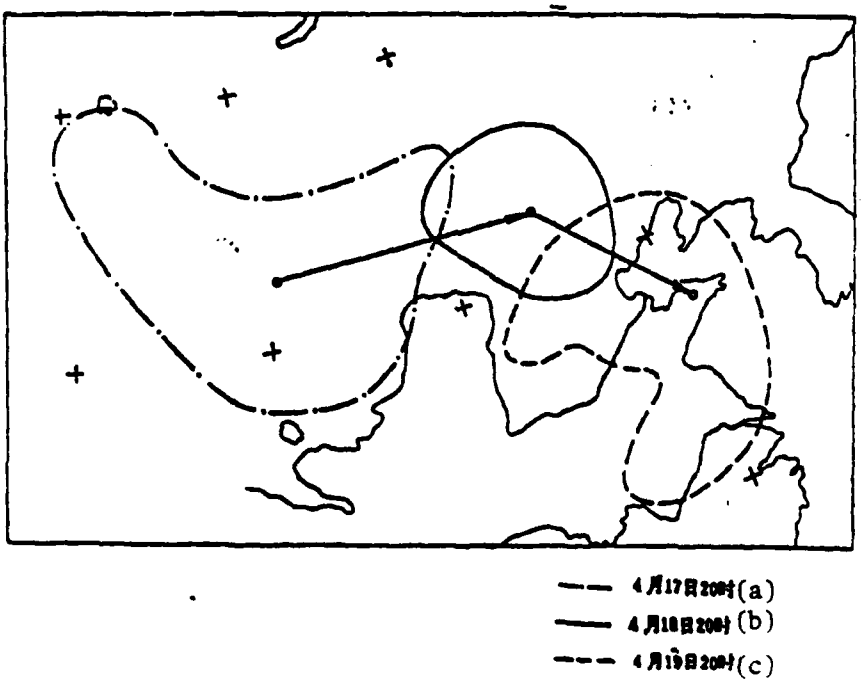

Fig. 1. Path of strong wind at 2000 hours on 17-19 April 1980.
Key: (a) At 2000 hours on 17 April; (b) At 2000 hours on 18 April; (c) At 2000 hours on 19 April.

IV. Properties of Atmospheric Boundary Layer During Dust Storm Process

A violent weather process can cause considerable variation of the structure of the atmospheric boundary layer; however, the structural variation of the atmospheric boundary layer may sometimes result in a certain weather phenomenon [4].

In the afternoon of 18 April 1980 during an intense dust storm in the near-ground layer, the structural variation of the atmospheric boundary layer was complex and violent.

Figure 2 is a time variation diagram of wind speed, temperature and humidity at the ground during the dust storm process. It is apparent from Fig. 2 that the average wind speed at the ground on 18 April was only 3 m/sec at 1700 hours; the wind speed increased rapidly to 13 m/sec at 1800 hours. Throughout the dust storm process, the maximum wind speed appeared at 0200 hours on the 20th; the wind speed (average for 10 minutes) was as high as 17 m/sec. Within three hours before 1800 hours on the 18th, the temperature rapidly rose to 8°C; after 1800 hours the temperature gradually decreased. From 1700 to 1800 hours on the 18th, the absolute humidity rapidly dropped by 7 mb.

Figure 3 shows the radio sounding data from 0100 to 1900 hours on 18 April. We can detect from the temperature curve that at 0100 hours there were two layers of temperature inversion. The altitudes at the top of the temperature inversion layer were, respectively, 700 and 2700 meters. A radiation temperature inversion formed by radiation cooling at the ground appeared at the 700-meter altitude; a descending temperature inversion due to the descending motion of upper-layer cold air appeared at the 2700-meter altitude. At 0700 hours, the altitude of the top of the descending temperature inversion layer was lowered to 1600 meters and the low-layer temperature inversion had disappeared. At 1300 hours, the top of the descending temperature inversion layer was lowered to 1100 meters in altitude; at 1900 hours the temperature inversion layer was entirely destroyed and the ambient temperature decreased as the altitude was higher in a simple harmonic way.

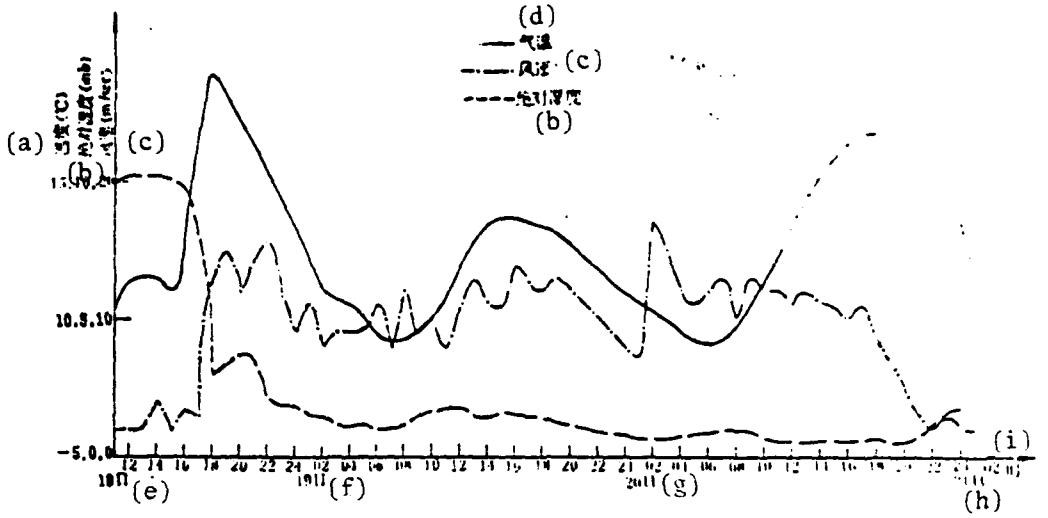

Fig. 2. Variations of wind speed, ambient temperature and absolute humidity with time above ground before and after dust storm (Madian station).
Key: (a) Temperature; (b) Absolute humidity; (c) Wind speed; (d) Ambient temperature; (e) On the 18th; (f) On the 19th; (g) On the 20th; (h) On the 21st; (i) Hours.

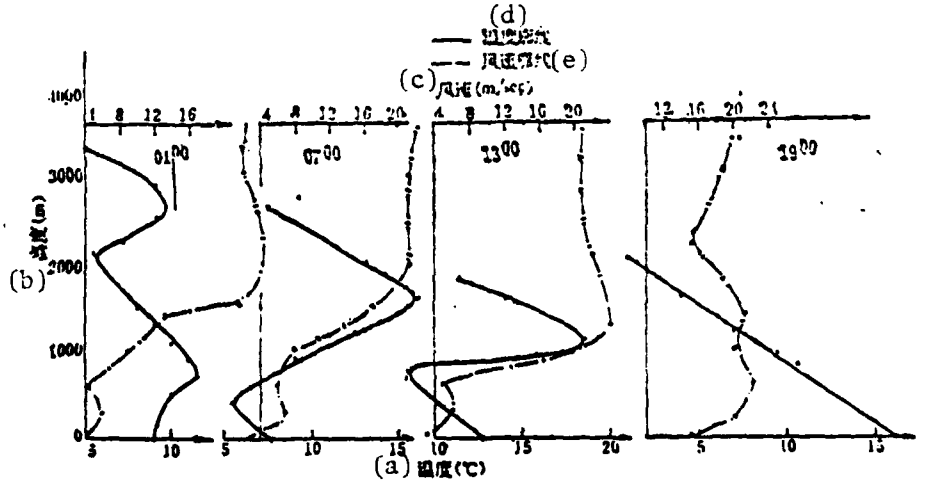

Fig. 3. Vertical distribution of temperature and wind speed from 0100 to 1900 hours on 18 April 1980.
Key: (a) Temperautre; (b) Altitude; (c) Wind speed; (d) Temperature contour; (e) Wind speed contour.

We can see from the aforementioned variation process of temperature contours, due to the southward motion of the high-altitude intense cold air, the temperature increase of the descending cold air formed a temperature inversion layer in the lower part of the troposphere; the altitude of the temperature inversion layer continuously decreased, and its intensity continuously increased. In the afternoon of the 18th (refer to temperature curve at 1300 hours in Fig. 3), a very intense temperature inversion layer formed in the vicinity of 1-km altitude. The existence of this temperature inversion layer restricted the vertical exchange of eddies. Therefore, the momentum of downward transport from the upper layers would be blocked and piled up in the upward portion at the top of the temperature inversion layer. Above (at 1300-meter altitude) the top of the temperature inversion layer, the wind speed was as high as 24 m/sec; however, below the top of the temperature inversion layer, the wind speed rapidly decreased. At the ground, the wind speed was only 3 m/sec.

This property of the atmospheric boundary layer is the cause of why particles brought over Beijing by high-altitude wind were blocked at high altitude, not to be transported to the near-ground layer. Therefore, the particles brought to Beijing from its upper stream zone of strong wind may float and mix at the high altitude for a long time. Due to the large amount of sandy soil particles in the high-altitude atmosphere, the sky was yellow while it was calm at the ground.

After 1300 hours on the 18th, the aforementioend physical process continuously developed downward. We can see from the observation data at the iron meteorological tower the continuous process of the temperature inversion layer from 1400 to 1800 hours on the 18th (refer to Fig. 4). For this duration, the vertical distribution of wind speed was shown in Fig. 5. We can see from Fig. 5 that the wind speed increased rapidly at altitudes higher than 200 meters from 1400 to 1700 hours; however, the wind speed varied only a little at altitudes below 100 meters.

Figure 6 shows the R_i number at the 200-meter altitude calculated by using the observation data at the meteorological tower. The definition of the

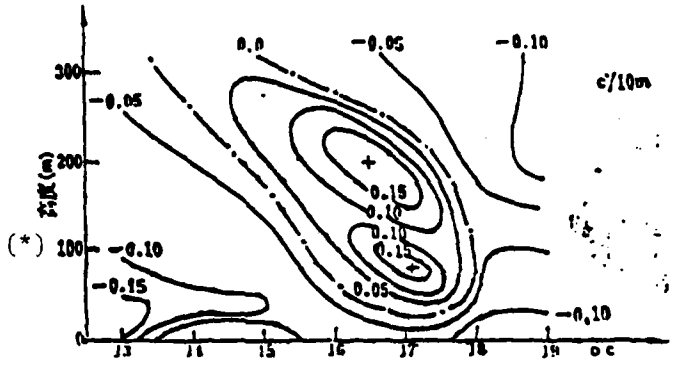

Fig. 4. Contour diagram of time with altitude for temperature stratification.
Key: (*) Altitude.

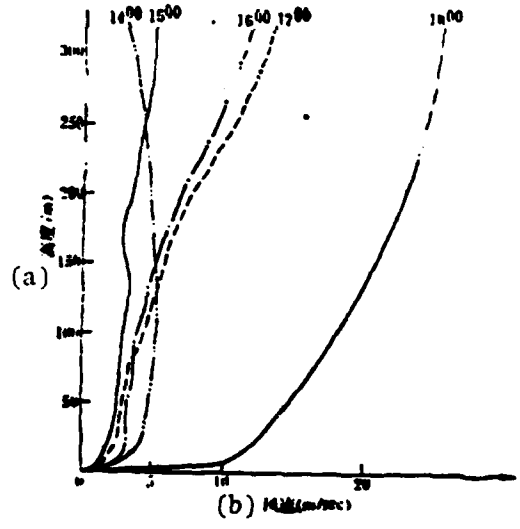

Fig. 5. Variation of wind speed profile with time.
Key: (a) Altitude; (b) Wind speed.

R_i number is $$R_i = \frac{g}{\theta} \frac{\frac{d\theta}{ds}}{\left(\frac{dV}{ds}\right)^2}.$$

In the equation, g is the gravitational acceleration; θ is the potential temperature; V is wind speed; and z is altitude. We can see from Fig. 6 that the R_i number were quite high from 1300 to 1400 hours on the 18th and the stratification was very stable. After 1400 hours, the R_i number decreased continuously. About 1700 hours, the R_i number reached the critical value of 0.25. At that time, the tangential shift of the wind speed was dynamically unstable and the energy of the wind speed tangential shift can easily be transformed into eddy energy. The intensification of vertical exchange of eddies caused the momentum of the upper layer to be rapidly transported downward. Figure 7 shows a time-space distribution diagram of momentum flux (τ/ρ, τ as the shear stress, and ρ as the air density) calculated from data observed from the meteorological tower. We can see from this diagram that the extreme-value momentum flux was rapidly transported to the near-ground atmospheric layer after 1700 hours on the 18th. Due to this intensification of vertical transport, aerosols in the upper layer were also rapidly transported to the ground. This was the physical reason that the dust storm broke out at ground level and the horizontal visibility rapidly decreased to altitudes below 1000 meters after 1700 hours on the 18th.

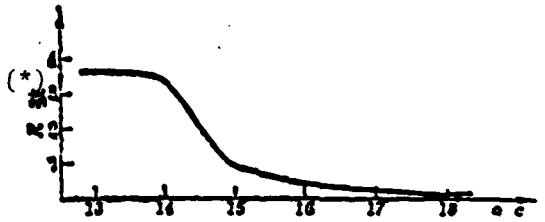

Fig. 6. Variation of R_i number with time at altitude of 200 meters.
Key: (*) R_i number.

V. Aerosol Properties During Dust Storm

Figure 8 shows the variation of aerosol concentration with time. We can see from the figure that the aerosol concentration varied between $4 \cdot 10^{-5}$ and $2.5 \cdot 10^{-4}$ grams per cubic meter. During the dust storm period, the aerosol

concentration was higher by one order of magnitude than in the period of calmness, and the highest value of aerosol concentration was $6.13 \cdot 10^{-3}$ grams per cubic meter.

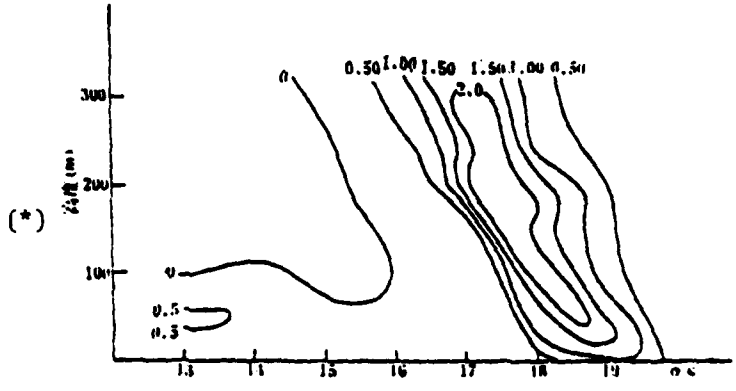

Fig. 7. Variation of τ/ρ with time and altitude measured on meteorological observation tower.
Key: (*) Altitude.

During the dust storm, the distribution of aerosol particle size was also significantly different from that of the calm time (see Fig. 9). During the calm time, among the distribution of aerosol particle size, the sizes smaller than 0.4μ are the major portion. During the dust storm, the maximum value in distribution of aerosol particle size was between 0.6 and 1μ. This explains a phenomenon that during a dust storm the aerosols are larger than that during a calm time.

Table 2 shows the elemental measurement results of aerosols collected from 16 to 21 April 1980. We can see from Table 2 that elements Eu and Ta only exist in dust storm aerosols. For the other elements, they are basically the same but the concentration of elements is generally higher than that before and after dust storm. From aerosol particle size distribution during a dust storm, the differences between elements and the elemental concentrations from that of calm time explains that there are different sources of aerosols during a dust storm and during calm time. In the following, the

authors tried to discuss the aerosol properties during a dust storm by utilizing the principle of ground geochemistry in order to explain the source of the dust storm.

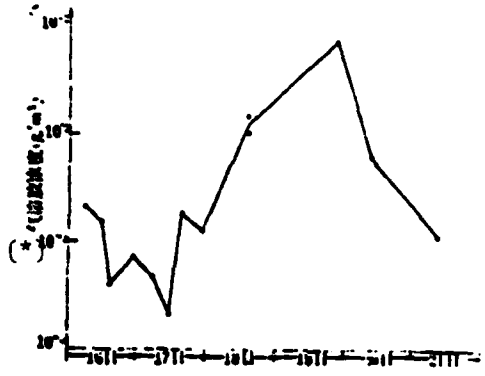

Fig. 8. Variation of aerosol concentration with time.
Key: (*) Aerosol concentration.

Under general conditions, there are two parts of main sources of microparticles entering the atmosphere: the first part includes those particles naturally produced on earth, such as ashes and dust erupted from volcanoes, salt particles entering the atmosphere from flying foam of seawater, and microparticles entering the atmosphere such as wind blown weathered materials and soil from the earth crust. The second part includes smoke dust from factories, transportation vehicles, and household coal or petroleum; this part is artificially produced. Internationally, the enrichment factor F_o was suggested by Gordon et al. [5] to determine and evaluate the elemental sources of elements in the atmosphere.

$$F_o = \frac{C_{e,air}/C_{Sc,air}}{C_{e,cr}/C_{Sc,cr}}$$

In the equation, $C_{e,air}$ and $C_{Sc,air}$ are, respectively, the elemental and Sc concentrations in the atmospheric aerosols; $C_{e,cr}$ and $C_{Sc,cr}$ are, respectively, the average concentrations of the particular element and Sc in the earth crust.

Internationally, Al and Fe are used as normalizing elements. Since the neutron activation method is used in this paper to measure elemental content, since the properties of the element Scandium are stable and it is not prone to vaporization and using the neutron activation method to measure and its precision is quite good, therefore, Sc is used as a normalizing element to calculate the enrichment factor. At the same time, when compared with carrying it out with a normalizing enrichment factor using Fe, both are basically identical. This work uses the average abundance of the elements in the earth's crust to calculate the enrichment factor of the various elements in atmospheric aerosols. The results are shown in Table 3. From the F_0 values shown it can be seen that the relative concentration of many elements in the aerosols and their relative concentration in the structure of the earth's crust are extremely similar. The F_0 values of Fe, Co, Cr, Rb and rare earth elemtns are all close to 1. The F_0 values of most elemnts are between 0.4 and 10. Only the F_0 values of such elements as Se, Sb, As, Br, W, and Mo are greater than 10.

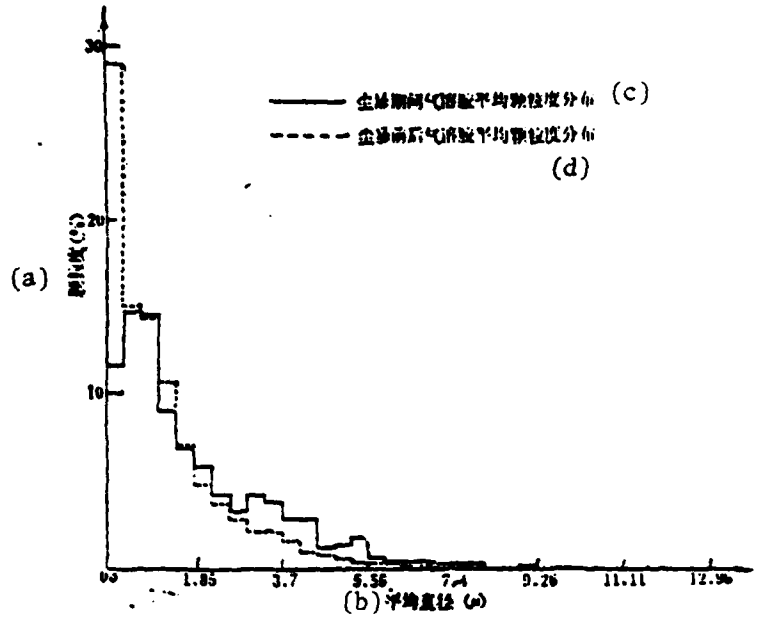

Fig. 9. Particle size distribution of aerosol. Key: (a) Granularity; (b) Average distribution of aerosol particle size during dust storm; (c) Average distribution of aerosol particle size before and after the dust storm.

Lautzy et al. [7] suggested that relative to the source from the earth crust, elements with atmospheric enrichment factors less than 10 are not considered as enrichment; however, elements with the atmospheric enrichment factors in the order of magnitudes between 10 and 10^4 are considered as enrichment. Based on this determination and the consideration that many factors in nature can influence the concentrations of elements in the atmosphere, it can be considered that the elements with enrichment factors close to 1 or smaller than 10 are mainly soil or dust from weathered rock materials blown by wind into the atmosphere. However, the elements with enrichment

Table 2. Trace elements in atmospheric aerosols on 16-20 April 1980.

(a) 元素 / (b) 样品	1	2	3	4	5	6	7	8	9	10	11	12
Sm	8.4×10^{-10}	1.3×10^{-9}	5.9×10^{-10}	6.1×10^{-10}	5.2×10^{-10}	1.6×10^{-9}	1.2×10^{-9}	8.1×10^{-10}	1.4×10^{-9}	3.3×10^{-9}	4.6×10^{-9}	8.7×10^{-10}
Hg	2.8×10^{-9}	3.3×10^{-9}	—	2.5×10^{-9}	3.0×10^{-9}	—	1.0×10^{-9}	—	—	—	—	1.8×10^{-9}
Co	1.1×10^{-9}	1.0×10^{-9}	8.9×10^{-9}	7.2×10^{-9}	6.6×10^{-9}	1.0×10^{-7}	1.7×10^{-7}	1.3×10^{-7}	1.8×10^{-7}	4.1×10^{-7}	8.7×10^{-8}	9.4×10^{-8}
Ce	2.4×10^{-9}	4.8×10^{-9}	1.9×10^{-8}	1.8×10^{-8}	1.8×10^{-8}	6.7×10^{-8}	3.1×10^{-8}	2.1×10^{-8}	4.2×10^{-8}	1.6×10^{-7}	1.1×10^{-7}	2.9×10^{-8}
Yb	—	—	—	—	—	—	4.5×10^{-10}	5.0×10^{-10}	5.3×10^{-9}	1.1×10^{-9}	1.8×10^{-9}	5.0×10^{-10}
La	5.8×10^{-10}	9.4×10^{-10}	4.4×10^{-9}	6.9×10^{-10}	1.1×10^{-10}	1.1×10^{-10}	1.3×10^{-10}	1.0×10^{-10}	1.8×10^{-9}	2.4×10^{-9}	3.8×10^{-10}	1.4×10^{-10}
U	5.0×10^{-10}	8.1×10^{-10}	8.0×10^{-10}	6.8×10^{-10}	5.1×10^{-10}	1.0×10^{-9}	6.5×10^{-10}	8.4×10^{-10}	6.8×10^{-9}	1.1×10^{-9}	2.0×10^{-9}	3.7×10^{-10}
Rb	—	2.0×10^{-7}	1.1×10^{-7}	9.1×10^{-8}	1.0×10^{-7}	1.6×10^{-7}	2.0×10^{-7}	8.3×10^{-8}	1.2×10^{-8}	3.1×10^{-8}	3.0×10^{-8}	1.7×10^{-8}
Th	2.2×10^{-9}	3.4×10^{-9}	1.3×10^{-8}	1.0×10^{-8}	1.5×10^{-9}	3.2×10^{-9}	2.0×10^{-9}	2.0×10^{-9}	2.0×10^{-8}	6.0×10^{-8}	8.0×10^{-8}	2.0×10^{-8}
Cr	1.2×10^{-8}	1.6×10^{-8}	7.0×10^{-8}	1.2×10^{-7}	9.4×10^{-8}	1.0×10^{-7}	1.0×10^{-7}	8.2×10^{-8}	1.7×10^{-7}	4.7×10^{-7}	4.6×10^{-7}	8.0×10^{-8}
Hf	7.0×10^{-10}	1.3×10^{-9}	4.0×10^{-10}	7.7×10^{-10}	—	9.0×10^{-10}	7.3×10^{-10}	8.3×10^{-10}	1.0×10^{-9}	2.7×10^{-9}	3.6×10^{-9}	9.0×10^{-10}
W	3.3×10^{-9}	5.1×10^{-9}	5.0×10^{-9}	—	1.0×10^{-9}	6.0×10^{-9}	3.7×10^{-9}	1.4×10^{-9}	2.3×10^{-9}	8.0×10^{-9}	6.3×10^{-9}	2.3×10^{-9}
As	1.5×10^{-8}	3.0×10^{-8}	3.0×10^{-8}	1.1×10^{-7}	4.5×10^{-8}	1.4×10^{-7}	1.0×10^{-7}	2.0×10^{-8}	3.0×10^{-8}	7.5×10^{-8}	1.1×10^{-7}	4.7×10^{-8}
Ca	1.0×10^{-8}	1.0×10^{-8}	6.0×10^{-8}	6.0×10^{-8}	5.1×10^{-8}	1.7×10^{-8}	8.0×10^{-8}	1.0×10^{-8}	4.0×10^{-8}	7.0×10^{-8}	—	8.0×10^{-8}
Br	7.3×10^{-9}	6.0×10^{-9}	3.0×10^{-8}	7.0×10^{-9}	4.0×10^{-9}	8.0×10^{-9}	6.1×10^{-8}	6.3×10^{-9}	8.2×10^{-9}	4.0×10^{-7}	7.1×10^{-9}	5.2×10^{-9}
Co	4.0×10^{-10}	7.0×10^{-10}	4.2×10^{-10}	4.0×10^{-10}	8.0×10^{-10}	1.5×10^{-9}	1.1×10^{-9}	8.6×10^{-10}	1.0×10^{-9}	4.3×10^{-9}	4.4×10^{-9}	1.0×10^{-9}
Tb	—	—	—	—	2.0×10^{-10}	4.0×10^{-10}	2.5×10^{-10}	1.0×10^{-10}	2.0×10^{-9}	8.0×10^{-9}	5.7×10^{-10}	—
Na	1.0×10^{-9}	2.0×10^{-9}	1.3×10^{-9}	1.4×10^{-9}	1.1×10^{-8}	3.0×10^{-7}	2.0×10^{-9}	1.0×10^{-9}	3.2×10^{-8}	8.1×10^{-8}	9.0×10^{-9}	1.0×10^{-9}
Ni	—	—	—	—	—	2.0×10^{-8}	2.7×10^{-8}	2.4×10^{-8}	1.1×10^{-7}	3.1×10^{-7}	—	—
Nb	1.3×10^{-8}	1.7×10^{-8}	1.7×10^{-8}	1.0×10^{-8}	—	2.0×10^{-7}	1.0×10^{-8}	—	2.0×10^{-7}	8.0×10^{-7}	1.0×10^{-8}	9.0×10^{-8}
Fe	3.2×10^{-8}	8.4×10^{-8}	3.2×10^{-7}	2.6×10^{-8}	2.1×10^{-8}	1.0×10^{-7}	6.0×10^{-8}	3.4×10^{-8}	7.7×10^{-8}	2.1×10^{-7}	2.4×10^{-8}	4.0×10^{-8}
Co	2.2×10^{-8}	4.0×10^{-8}	2.0×10^{-8}	2.7×10^{-8}	2.0×10^{-8}	5.0×10^{-8}	4.3×10^{-8}	2.5×10^{-8}	3.7×10^{-8}	8.2×10^{-8}	1.2×10^{-8}	2.0×10^{-8}
Mn	1.0×10^{-7}	1.5×10^{-8}	6.0×10^{-7}	6.0×10^{-7}	8.0×10^{-7}	2.1×10^{-8}	1.4×10^{-8}	1.7×10^{-8}	7.7×10^{-8}	3.0×10^{-8}	6.7×10^{-8}	8.7×10^{-8}
Nd	—	—	—	—	—	—	—	—	1.2×10^{-7}	2.1×10^{-7}	—	2.7×10^{-8}
K	1.0×10^{-8}	2.0×10^{-8}	1.0×10^{-8}	1.3×10^{-8}	1.7×10^{-8}	3.0×10^{-8}	2.0×10^{-8}	2.9×10^{-8}	3.6×10^{-8}	8.0×10^{-8}	1.1×10^{-7}	2.1×10^{-8}
Eu	—	—	—	—	—	—	—	—	3.1×10^{-8}	8.2×10^{-8}	—	—
La	6.1×10^{-9}	8.0×10^{-9}	4.2×10^{-8}	4.0×10^{-9}	3.0×10^{-9}	1.0×10^{-7}	7.0×10^{-9}	6.4×10^{-9}	8.7×10^{-8}	1.0×10^{-7}	2.0×10^{-7}	9.0×10^{-8}
Sb	3.2×10^{-9}	4.0×10^{-9}	9.2×10^{-10}	1.1×10^{-9}	1.7×10^{-9}	4.1×10^{-9}	2.0×10^{-9}	6.6×10^{-9}	4.2×10^{-8}	7.0×10^{-8}	—	2.5×10^{-9}
Sc	2.4×10^{-9}	3.0×10^{-9}	—	—	2.3×10^{-9}	2.3×10^{-9}	2.0×10^{-9}	3.0×10^{-9}	1.3×10^{-8}	6.0×10^{-8}	4.0×10^{-9}	—
Ta	—	—	—	—	—	—	—	—	1.5×10^{-9}	4.2×10^{-9}	—	—

Remark: Sample nos. 1-4 were four samples collected on 18 April; sample nos. 5-8 were four samples collected on 17 April; sample nos. 9, 10, 11 and 12, were, respectively, samples collected on 18, 19, 20 and 21 April.
Key: (a) Element; (b) Sample.

Table 3. Enrichment factors of elements in atmospheric aerosol.

(a) 元素 \ (b) 样品	1	2	3	4	5	6	7	8	9	10	11	12
Se	1811	660	—	—	921	426	529	984	17.9	37.5	225	—
Sb	196	169	78	864	1700	133	167	376	14.4	9.5	—	163
As	194	96	37	88	61	52	60	26	12	12	14	33
Br	38	19	24	49	37	23	22	49	2.5	4.9	6.5	25
W	27	18	37	—	20	24	22	11	11	1.2	9.6	19
Mo	20	18	—	26	40	—	11	—	—	—	—	15
Ca	7.1	8.2	7.8	8.1	9.2	7.3	8.6	6.9	7.0	9.6	6.1	8.6
Ce	8.1	8.9	8.5	8.2	8.8	3.3	3.5	7.7	2.1	1.4	—	6.5
Ba	—	8.2	4.4	3.4	4.7	2.4	4.1	2.3	1.9	2.0	2.0	4.9
U	2.7	2.6	3.8	3.9	3.8	2.4	2.1	3.8	1.3	1.1	2.4	1.7
Th	2.8	3.9	2.3	2.9	3.1	2.2	2.6	2.4	2.1	2.0	2.1	2.6
Hf	3.1	3.7	2.7	4.0	—	2.1	2.1	2.4	2.3	2.5	2.7	3.7
Cs	1.9	2.2	2.4	2.5	5.7	3.2	3.2	3.3	3.7	3.9	3.4	4.1
Rb	1.8	1.8	1.4	1.7	—	1.9	1.8	—	1.5	1.9	1.8	1.3
Co	1.8	1.8	1.8	1.7	2.0	1.4	1.5	1.2	1.9	1.0	1.1	1.4
Cr	1.8	1.4	1.3	1.9	1.9	1.2	1.7	1.8	1.2	1.3	1.0	0.8
Ni	—	—	—	—	—	2.2	3.2	3.7	1.9	1.1	—	—
La	2.5	2.5	2.4	2.5	2.5	2.2	2.3	2.1	2.9	1.4	2.0	2.3
Ce	2.2	2.3	2.3	1.9	2.8	1.9	2.5	2.5	2.1	1.9	2.2	1.9
Sm	1.7	1.8	1.7	1.8	1.7	1.7	1.8	1.6	1.6	1.5	1.7	1.8
Yb	—	—	—	—	—	—	1.3	2.2	1.2	1.0	1.4	2.4
Tb	—	—	—	—	5.5	3.4	2.5	2.3	2.0	2.0	2.2	—
Eu	—	—	—	—	—	—	—	—	1.8	1.8	—	—
Nd	—	—	—	—	—	—	—	—	3.0	2.0	—	—
Ia	1.4	1.5	1.5	2.2	4.4	1.4	2.3	2.3	1.4	1.3	1.8	3.4
Fe	0.7	0.8	1.0	0.7	0.8	0.9	0.7	0.7	1.0	1.0	1.0	1.0
K	1.1	1.0	1.3	1.0	1.0	1.2	1.1	1.1	1.2	1.2	1.2	1.2
Na	0.4	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.4	0.6	0.5
Ta	—	—	—	—	—	—	—	—	0.5	0.6	—	—

Key: (a) Element; (b) Sample.

factors greater than 10 can be considered released from human activities, not from materials of the earth crust. However, in the dust storm aerosols on the 18th and 19th, the enrichment factors of these elements, such as Se, Sb, As, Br and W, had an obvious decreasing trend compared to calm time, and the F_c values of elements in samples collected on the 20th and 21st again increased and returned to the levels before the dust storm. The variations of these values reveal a situation that at the same location, the aerosol

samples collected during and after a dust storm had different elemental sources. Therefore, the authors compared concentrations of these elements in the atmosphere with the average concentrations in coal, and calculated their enrichment factors (refer to Table 4). In the result, it was revealed that the elements such as Se, As, Br and Sb with relatively high enrichment factors, are small relative to those in coal. This means that most of these elements released to the atmosphere are caused by combustion of household or industrial coal. Therefore, the reason that the enrichment factors of these elements tended to decrease on the 18th and the 19th is the composition of micro-particles from the sandy soil. At that time, the contribution from coal was minimized, not that outstanding. At the same time, from the appearance of the collected samples of aerosol micro-particles, there also were obvious differences. During calm time, the collected samples were grayish black; however, the aerosol samples during the dust storm was dull yellow. Based on the data of the presently available aerosol elements and the relationship of weather processes discussed previously, it can be considered that the main sources of aerosol due to this dust storm over Beijing were sandy soil micro-particles from the area originating the strong wind of the dust storm and from the area of the route of movement of the dust storm as these micro-particles were blown up by wind and mixed in the high altitudes.

VI. Conclusion

From discussions of weather background and boundary layer structure of the dust storm process in spring 1980, and analysis of aerosol characteristics during the dust storm, preliminarily the following conclusions can be drawn:

1. The aerosol concentration during the dust storm was higher by one order of magnitude than the aerosol concentration during calm time. The extreme values of distribution of aerosol particle sizes were between 0.6 and 1.0μ; this was greater in particle size than that in calm time.

2. As revealed from analysis of elemental concentrations in the aerosol, the elements Eu and Ta only exist in dust storm aerosol; basically there is

Table 4. Enrichment factors of elements with respect to coal.

(a)元素 \ (b)样品	1	2	3	4	5	6	7	8	9	10	11	12
Se	24	8.8	—	—	12.3	5.7	7	12	0.2	0.5	3	—
Sb	0.7	0.6	0.3	3.1	5.2	0.5	0.6	1.4	0.1	0.1	—	0.6
As	43	40	15	41	21	21	21	11	4.9	4.8	5.9	14
Br	4.6	2.4	3.1	6.4	4.6	3.0	2.8	5.6	0.3	0.5	0.8	3.4
Ca	2.4	2.8	2.7	2.1	3.2	2.5	2.3	2.0	2.4	3.4	2.1	3.0
Ca	4.4	3.1	3.0	2.9	3.7	1.8	1.9	4.2	1.2	0.8	—	3.6
Hf	0.7	0.9	0.6	0.9	—	0.5	0.5	0.6	0.5	0.0	0.6	0.9
U	1.3	1.2	1.8	1.9	1.9	1.2	1.0	1.7	0.6	0.5	1.2	0.8
Th	1.2	1.3	1.0	1.3	1.4	1.0	1.1	1.0	0.9	0.9	0.9	1.1
Cs	1.2	1.5	1.6	1.7	2.2	2.2	2.1	2.2	2.4	2.6	2.2	2.7
Rb	2.4	2.2	2.0	2.4	—	2.6	2.4	—	2.1	2.7	2.5	1.9
Co	2.2	2.3	2.5	2.4	2.8	2.0	2.2	1.6	1.4	1.4	1.6	1.9
Cr	1.8	1.6	1.6	2.3	2.3	1.5	2.0	1.2	1.4	1.5	1.3	1.0
La	0.9	0.9	0.8	0.9	0.9	0.7	0.8	0.7	0.7	0.5	0.7	0.8
Ce	0.8	0.8	0.8	0.7	1.0	0.7	0.9	0.9	0.7	0.6	0.8	0.7
Sm	0.7	0.8	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.6	0.7	0.7
Yb	—	—	—	—	—	—	0.9	1.5	0.8	0.7	0.9	1.7
Tb	—	—	—	—	3.3	2.1	1.5	1.2	1.2	1.2	1.3	—
Eu	—	—	—	—	—	—	—	—	0.7	0.7	—	—
Nd	—	—	—	—	—	—	—	—	1.2	0.8	—	4.9
Lu	0.9	1.0	1.0	1.4	2.8	0.9	1.4	1.5	0.9	0.8	1.0	2.2
Fe	1.6	1.9	2.2	1.7	1.7	2.0	1.7	1.6	2.2	2.4	2.3	2.3
K	1.8	1.7	2.2	1.6	2.7	2.0	1.8	1.9	2.0	1.9	2.0	2.1
Na	2.2	2.3	2.5	2.4	2.8	2.0	2.2	1.6	1.4	1.4	1.6	1.9
Ba	—	2.5	2.1	1.6	2.3	1.2	2.0	1.1	0.9	1.0	1.0	2.4
Ni	—	—	—	—	—	1.7	2.4	2.9	0.8	0.9	—	—
Ta	—	—	—	—	—	—	—	—	0.6	0.6	—	—

Key: (a) Element; (b) Sample.

the same situation for other elements but relatively greater variation in concentrations. As revealed from calculation of enrichment factors, the major source of elements Se, As, Br and Sb in aerosol was from coal combustion.

3. During the dust storm, the structure of the atmospheric boundary layer had obvious variations. The descending motion of high-altitude cold air after passage of the cold front formed an intense temperature inversion layer in the upper part of the atmospheric boundary layer. This temperature inversion layer restricted the vertical exchange of eddies; momentum above the tempera-

ture inversion layer and micro-particles of sandy soil floating with wind cannot be transported toward the ground. This was the reason that for several hours before the intense dust storm at the ground, the sky turned to yellow while the ground wind force was very small. The duration for maintaining this situation depends on the stability of the low-layer atmosphere. When the Richardson number R_i of the low layers reaches 0.25, the shearing dynamic force of the wind speed is not stable, and then the temperature inversion layer is rapidly destroyed. The high-altitude momentum and aerosols in large quantities are then transported downward, forming a strong wind and dust storm at the ground.

4. From the analysis of the weather background of the dust storm process, and the analysis of elemental concentrations in aerosol, it can be considered that the sources of dust storm aerosol in spring in Beijing are complex. The major sources are sandy soil micro-particles blown by the wind into the high altitude in the upper-stream northwestern area of Beijing for the formation of a strong wind, and the area of the wind moving route. However, when the strong wind of the dust storm passed over the Beijing area, there are also micro-particles from local sandy soil entering the atmosphere. Therefore the dust storm aerosol forms because these sandy soil micro-particles are blown by the wind into the atmosphere and mixed at high altitudes. Since the dust storm strong wind is a very strong northwesterly, the aerosol expelled by human activities is quickly blown by the wind out of the Beijing area, transported to the lower stream areas.

As the data collected by us are limited, the aforementioned conclusions are only preliminary. The source of the dust storm is a problem of relative complexity; we prepare to discuss the problem further in future work.

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